EFFECT OF USED GROUND COPPER SLAG IN PROPERTIES OF CONCRETE DESIGN

By

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Dissertation submitted in partial fulfillment of

the requirements for the

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

FATIN NABILAH BT RAZALI

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In the Name of Allah, The Most Merciful and Compassionate, praise to Allah, He is the Almighty. Eternal blessings and peace upon the Glory of the Universe, our Beloved Prophet Muhammad (S.A.W), his family and companions.

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ABSTRACT

Application of mineral, agricultural and industrial wastes in concrete manufacturing are being popular and most have proved to be beneficial in enhancing the characteristics of concrete. Used Copper Slag is an industrial waste that is hazardous in nature and its safe and legal dispose is an issue. The earlier research found that used copper slag on concrete was quite encouraging and behaves as a good pozzolan and as a cement replacement. For this project, 5% to 30% of copper slag had been tested as cement replacement up to 120 days to obtain the behavior and effect of the copper slag in strength and durability due to percentage of copper used and ages. Compressive and split tensile tests are tested to define the strength, while porosity is tested to define the durability. Result shows that it develops strength over a longer period, leading to reduce porosity and better durability. The reliability and consistency of the three (3) tests shows that 10% of copper slag as cement replacement is the maximum value for optimum strength and durability of concrete can be achieved.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Copper slag is used as an abrasive in shot blasting to prepare steel surfaces for painting (Benson et al, 1986). The widespread use of lead and other heavy metals in protective paints increases heavy metals in used slag, which is classified as a solid/hazardous waste. Landfill disposal of copper slag is not feasible since a few hundred tonnes are produced per year per factory; leaching of heavy metals into ground water is of concern. Solidification or stabilization is an increasingly attractive alternative to the remediation of improperly discarded hazardous or toxic materials, and is particularly effective when these toxic compounds are bound into a form immune to leaching. Solidification or stabilization basically involves waste containment within a solid matrix using different binder materials such as cement, pozzolans, clay and polymer. It is a treatment process that produces a solid monolithic or soil-like mass from a waste and leads to a product with improved structural integrity and physical characteristics (Montgomery et. al, 1988). It is a relatively new treatment process that has the potential to reduce leachability of hazardous constituents from the disposed waste.

1.2 Problem Statement

Based on the experience during internship at Malaysia Marine Heavy Engineering, Pasir Gudang, Johor, there is a mountain of copper slag at the disposal area. This amount of copper slag become more and more every year that come to the problem of not enough space to damp it. From the problem, it gave some idea to come out with the solution to reuse the wasted material in the concrete structure as a cement replacement. Investigations relating to the disposal of industrial by-products in concrete have been actively pursued. The disposal of these materials in concrete conserves natural resources and energy, and reduces pollution. However, the research work on copper slag has not been extensive. Copper slag has been used as an aggregate and backfilling material (Das et. al, 1983, Madany et.al, 1991, Roper et. al, 1983, and Zin, 1996). A few studies (Montgomery et. al, 1988, Tashiro, 1977, and Poon et. al, 1986) have been performed to investigate the stabilization of heavy metals present in copper slag within the cement matrix. It is noticed, however, that most studies were conducted on non-ground slag. In cases where ground slag was used, the slag was normally not contaminated with other waste. Therefore, it is felt that further studies need to be performed to justify cement-based solidification/stabilization for the safe disposal of ground copper slag (wasted).

The present studies embrace the safe disposal of the ground copper slag using cement-based solidification/stabilization as well as the potential reuse of the end product as construction material. The leachability of heavy metals, compressive strength of copper slag in concrete and the effects of the heavy metals on the hydration of the copper slag concrete are reported.

1.3 Objective and Scope of Study

1.3.1 Objectives

The objectives of this study are to investigate:-

- the behavior of ground copper slag in the concrete design
- the strength and durability of the concrete, and
- the potential of copper slag as cement replacement for some economical and environmental friendly.

1.3.2 Scope of Study

In order to achieve this objective, a few tasks and research need to be carried out. Some studies should be done on the properties, behavior, and effects of the copper slag on fresh properties of concrete. X-ray Fluorescence (XRF) and X-ray Diffraction (XRD) tests need to be conduct to determine the chemical composition and physical characteristic of the copper slag. For the behavior and effects of the copper slag in concrete, the compressive strength, elastic properties, and durability tests need to be conduct. Recommendations are to be made based on the findings of this study and results of the laboratory work done.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Copper Slag

Copper Slag is produced from a by-product of the manufacturing of copper, which is processed into an abrasive by Opta Minerals. Typically it is composed of ferrosilicate (Fayalite, Fe_2SiO_4) material and oxides, formed when the molten slag is quenched in cold water. This cooling process fractures the slag into coarse and angular particles, making it an ideal blasting slag with optimal blasting properties. Large quantities of slag are produced as a by product of metallurgical operations, resulting in environmental concerns with disposal. Blast-furnace slag is associated with iron production, has been effectively used as cementitious material in concrete. Long-term performance records of blended cements have demonstrated iron blast furnace slag to be economical and durable. Major copper producing regions of the United States (US) are located in the southwestern states where large quantities are generated as a by-product of the smelting operation. Copper slag aggregates have been widely used in base construction, railroad ballast, and engineered fill. Previous studies have shown that the use of ground copper slag (GCS) enhances the hydration reactions of a cementitious mixture. A study of different non-ferrous slag such as copper, nickel, and lead has indicated that copper slag has the potential for application as a cementitious material. Although it has successfully been used in ground form as a concrete mineral admixture in Canada, Europe, and Australia, the construction industry in the US has been slow in adopting this slag. There is a considerable interest in Southwestern US to use GCS as a partial substitute of portland cement since custom smelters are capable of producing as much as half a million tons of copper slag per year. By evaluating its potential use in concrete, there is an opportunity for both the copper and construction industries to benefit from using this material.

Studies on copper slag:

- Increase the compressive and tensile strength of concrete
- Refinement of porosity
- Improvement of durability (sulfate attack, alkali silica reaction)

2.1.1 Characterization of Ground Copper Slag (GCS)

2.1.1.1 Physical Properties

The copper slag is a by-product of operation of reverberatory furnaces. A large amount of concentrate, up to about 300 tons, may be placed in the furnace at one time. Impurities form a less dense liquid floating on top of the copper melt. These impurities include iron, lime, silica, and form the slag. The slag is skimmed off the top, while the melted material which has up to 50 percent copper, is called matte. The copper matte goes through a converter to blow forced air into it. The air forces silica back into the copper matte to collect the impurities and make more slag. The slag is skimmed off and air cooled. The slag is subjected to a process of staged crushing using jaw and impact crushers and screened to achieve a uniform and angular particle shape. The specific gravity of GCS as measured by ASTM C128 is around 3.5. The size distribution measured using a sonic sifter indicated that about 50% of the particles are smaller than 50 mm and 70% smaller than 100 mm. The average Blaine fineness was 270 m^2/kg, which may be converted to a specific surface area of the grains per unit of volume. A specific surface area of 9450 cm^2/cm^3 for the slag and 10,900 cm^2/cm^3 for a typical Type I portland cement (Blaine fineness: 346 m^2/kg) was obtained indicating that GCS is as fine as a Type I portland cement.

2.1.1.2 Chemical Composition

It was observed that the copper content is limited to 1-2% of the production of the smelter and may be present in the form of metallic copper, or cuprite (copper silicate). Based on an oxide analysis, the present slag contained approximately 35% SiO_2 , 53% Fe_2O_3, in the terms of fayalite and magnatite, in addition to 3.3% CaO and 5.0% Al_2O_3. Other oxides of silicon, aluminum, calcium, and magnesium constituted the remainder of the GCS. Summation of the three reported-as-oxides of 3 iron, silicon, and calcium exceeded the 70-percent level specified by ASTM for pozzolanic materials. The chemical composition of Copper Slag in Pasir Gudang, Johor was been tested and the result of the composition was attached in the ***Appendix 1***.

2.2 Cement

Portland cement is the most common type of cement in general usage in many parts of the world, as it is a basic ingredient of concrete, mortar, stucco and most non-specialty grout. Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates ($3CaO.SiO_2$ and $2CaO.SiO_2$), the remainder consisting of aluminium and iron containing clinker phases and other compound.

Major Constituents of Portland Cement:

$3CaO.SiO_3$, C_3S	Tricalcium silicte
$2Ca.SiO_3$, C_2S	Dicalcium silicate
$3CaO.Al_2O_3$, C_3A	Tricalcium aluminate
$4CaO.Al_2O_3.Fe_2O_3$, C_4AF	Tetracalcium aluminoferrite

2.3 Pozzolan

Pozzolan is an inert silicious material which, in the presence of water, will combine with the lime to produce a cementitious matter with excellent structural properties. Examples of pozzolan are fly ash, fume and blast furnace slags.

Advantages of Pozzolans:

- Improved workability
- Economy
- Reduced Alkali-aggregate Reaction
- Increased Sulfate Resistance

2.4 Hydration

2.4.1 Hydration of Portland Cement

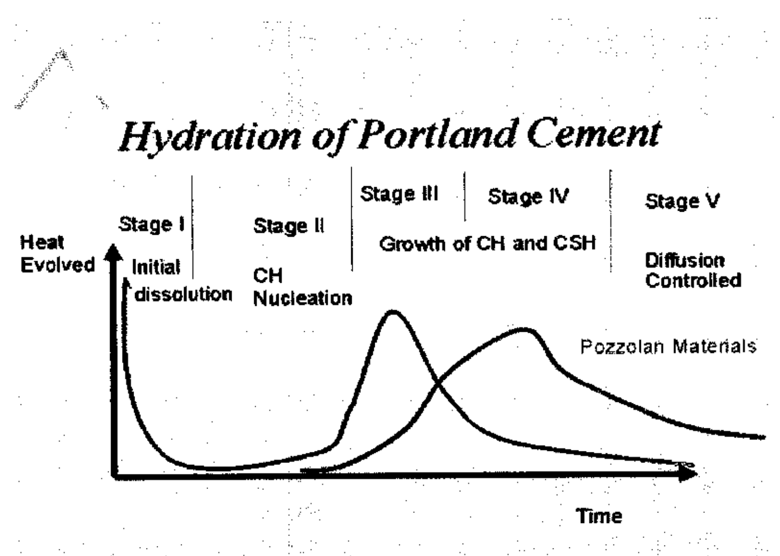

Figure 2. 1- **Hydration of Portland Cement (Tixier et. al)**

2.4.2 Effect of Copper Slag on the Hydration of Blended Cementitious Mixtures

Effect of copper slag on the hydration of cement based materials is studied. Up to 15% by weight of copper slag was used as a Portland cement replacement. Activation of pozzolanic reactions was studied using up to 1.5% hydrated lime. Hydration reactions were monitored using quantitative X-Ray diffraction (QXRD) and the porosity was examined using mercury intrusion porosimetry (MIP). Results indicate a significant increase in the compressive strength for up to 90 days of hydration. A decreases in capillary porosity measured using MIP indicated densification of the microstructure. The embrittlement due to the addition of slag is measured using fracture parameters. Fracture properties such as critical stress intensity factor, and fracture toughness, Gf showed a constant or decreasing trend with the addition slag.

2.5 Copper Slag as Cement Replacement

A study of different non-ferrous slags such as copper, nickel, and lead has indicated that copper slag has the potential for application as a cementitious material. The principal use is as Cement replacement (when ground), replacing 30-50% of Portland Cement in 'normal' concrete, but can replace up to 70% in specialist applications such as marine concrete. The summation of the three oxides (CaO+SiO2 +FeO) in copper slag exceeds the 70 percentile requirement of pozzolanic activity. This number compares various pozzolans for their degree of reactivity as compared to class C flyash. Utilization of copper slag for applications such as Portland cement replacement in concrete, and/or as a cement raw material has the dual benefit of eliminating the costs of disposal, while lowering the cost of the concrete. The physical and chemical properties of OPC and CS that were determined from a previous study (Al-Jabri et. al, 2002) are given in Table 2.1 and Table 2.2, respectively.

Table 2. 1 - **Physical properties of ordinary Portland cement and copper slag**

Test type	**Material**	
	Ordinary Portland cement	Copper slag
Fineness (cm^2/g)	3357	1261
Specific gravity	3.15	3.45
Initial setting (min)	110	250

Table 2. 2 - **Chemical composition of ordinary Portland cement and copper slag**

Component	**Ordinary Portland cement (%)**	**Copper slag (%)**
SiO_2	20.85	33.05
Al_2O_3	4.78	2.79
Fe_2O_3	3.51	53.45
CaO	63.06	6.06
MgO	2.32	1.56
SO_3	2.48	1.89
K_2O	0.55	0.61
Na_2O	0.24	0.28
TiO_2	0.25	0
Mn_2O_3	0.05	0.06
CI	0.01	0.01
Loss on ignition	1.75	0
IR	0.21	0
CuO	0	0.46
$Al_2O_3 + SiO_2 + Fe_2O_3$	29.14	89.29

Chemical analysis of Copper Slag and Portland cement is shown in *Table 2.2*. Ordinary Portland cement has a lime content of 63%, whereas copper slag has a very low lime content of ≈6%. This indicates that Copper Slag alone are not highly chemically reactive materials in order to be used as cementitious materials because Copper Slag must have a sufficient quantity of lime to reach the required rate of hydration and to achieve the required early age strength. Therefore, in this case, it would be more beneficial if copper slag could be chemically activated in order to increase its pozzolanic reaction.

2.6 Effect of Copper Slag in Concrete

2.6.1 Compressive Strength

The three oxides (CaO+SiO2 +FeO) in copper slag exceed the 70 percentile requirement of pozzolanic activity. Pozzolan is an inert silicious material that can produce a cementitious matter in excellent structural properties. It can improve workability, reduce alkali-aggregate reaction, and increase sulfate resistance that can affect the strength of the concrete. The compression test results show that the strength is increase when 5 to 10% copper slag is added as cement replacement.

2.6.2 Durability

2.6.2.1 <u>Porosity</u>

Concrete containing ground granulated slag develops strength over a longer period, leading to reduced permeability/ porosity and better durability properties. Since the unit volume of Portland cement will also be reduced, concrete is less vulnerable to alkali-silica and sulfate attack.

2.6.3 Elastic Properties

2.6.3.1 Tensile Strength

Tensile strength of a material is the maximum amount of tensile stress that it can be subjected to before failure. Copper Slag helps in increasing the tensile strength of the concrete. When the tensile strength is increase, the possibility of the material to be failure is smaller. The duration taken for material achieve the limit of failure also increase.

CHAPTER 3
METHODOLOGY

3.1 Approach to Solutions and Methodology

i. Problem Definition
ii. Preliminary Research
iii. Design
iv. Laboratory Work
v. Analysis of Findings
vi. Realibility and Effeciency

3.1.1 Problem Definition

- Clarifying Objectives
- This project has three main objectives that are to investigate the reused of copper slag in the concrete design, enhance the strength of the concrete, and as a cement replacement for some economical and environmental friendly

- Background study
- The idea of this project is enhanced by the fact that the amounts of wasted copper slag from blasting work at disposal area increasing year by year without any recycle used. The material is very significant in construction field and from some studies the compound in the copper slag is very useful and the wasted copper slag can be recycling back.

- Coming out with new concept
- From the objectives and background study found, some idea to use back the wasted of copper slag in the concrete mix had been found. The concept is to use

the copper slag as a cement replacement to enhance the behavior of concrete design which is not only can solve the problem of the disposal of the material but it is more economical way and environmental friendly.

3.1.2 Preliminary Research

- Using accessible resources (Internet, Library)
- The first research is done from sources like websites and books to find some related information and theories such as physical properties and chemical composition of copper slag, effect of the material in concrete mix, and the advantage of using the cooper slag in construction materials.

- Obtaining a clear view of this troubleshooting project
- The initiative basic and main concept that should be implemented is determined to avoid problems and confusion in the coming tasks.

- Meeting up with supervisor
- There are some discussion with supervisor about the topic to get more information and helped in contributing to the preliminary stage of this project.

3.1.3 Design

- Establishing design specifications
- The design is drafted out conceptually based on the procedure of concrete mix design. This concrete mix design is calculated to determine the suitable water cement ratio, and the proportion for aggregate and ground copper slag used. After had been review and got the approval from supervisor, the design is been proceed to the experimental/laboratory work.

3.1.4 Laboratory Work

- Testing of the composition

- Before start with the concrete work, there are some tested to be done. The copper slag had been sent to the laboratory to determine the X-ray Diffraction (XRD) and X-ray Fluorescence (XRF) to determine the physical characteristics and chemical composition of the material.
- Testing Methods:

i. X-ray Diffraction (XRD)

- X-ray diffraction techniques are based on the *elastic* scattering of x-rays from structures that have long range order. The most comprehensive description of scattering from crystals is given by the dynamical theory of diffraction.
- Powder diffraction (XRD) is a technique use to characterize the crystallographic structure, crystallite size (grain size), determining strains in crystalline materials, and preferred orientation in polycrystalline or powdered solid samples. Powder diffraction is commonly used to identify unknown substances, by comparing diffraction data against a database maintained by the International Centre for Diffraction Data.

ii. X-ray Fluorescence (XRF)

- X-ray fluorescence (XRF) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. The phenomenon is widely used for elemental analysis and chemical analysis, particularly in the investigation of metals, glass, ceramics and building materials, and for research in geochemistry, forensic science and archaeology.

- Sample making

- After composition of the material is known, concrete mix is proceeding. The concrete samples are done for some testing to know the result of the project. This is most important stage and takes a long time to get the results.

3.1.5 Analysis of Findings

- Reporting and record the results

- The result of the laboratory test are being updated and recorded from time to time based on the time schedule of the experiment.

- Analyze the results

- The results are analyzed and compare in graph schematic. Based on that, some conclusion can be made up.

3.1.6 Reliability and Efficiency

- Comparison of the result

- The theoretical and experimental results are compared. To ensure it is reliable, the experimental results obtain must be equal or approximately equal to the theoretical of the project.
- If the project is confirmed reliable, the tested done must be observed deeper, so that the efficiency of the samples can be recognized.

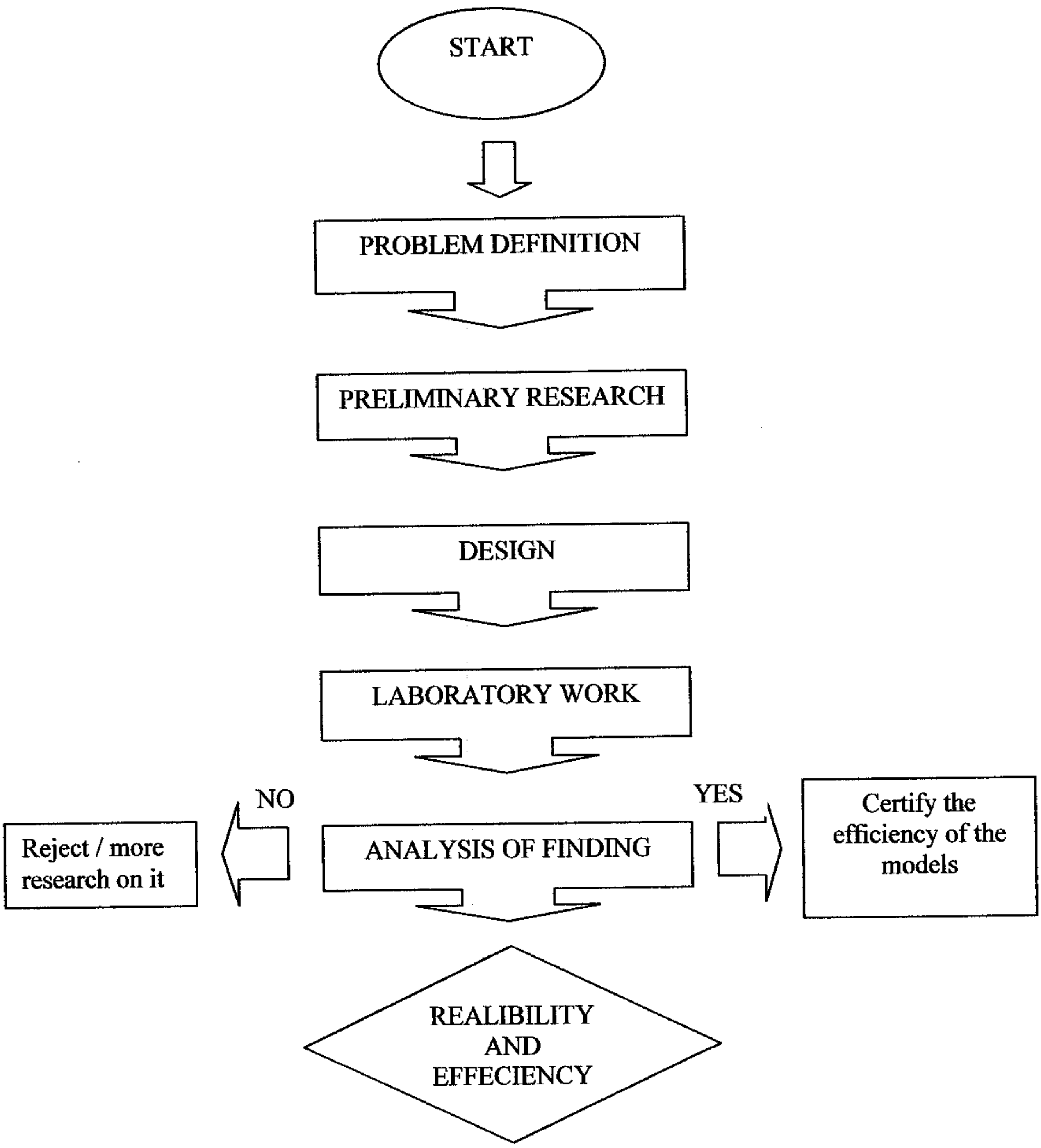

Figure 3. 1- **Schematic Work Flow**

3.2 Sample Preparation

3.2.1 Procedures:

3.2.1.1 Preparation of the material

- The materials used for mix design are cements, fine aggregate, course aggregate, water, and copper slag. There are three types of samples should be done which are cube test, split cylinder, and plank slab. Each sample has seven trials to be test for certain duration. The proportion of each material is based on the calculation design that had been made before this. For materials proportion calculation is attached in *Appendix B.*

3.2.1.2 Mixing

- The aggregates were mixed in the mixer for 1minute.
- The cements, copper slag and half of the water were added into the mixer and mix for 8 minutes.
- Another half of the water is added and mix for 1 minute.
- The mixer was stopped and slump test (60 ±5) was done before it can be use for casting.
- Equipment used: Mixer and Slump test

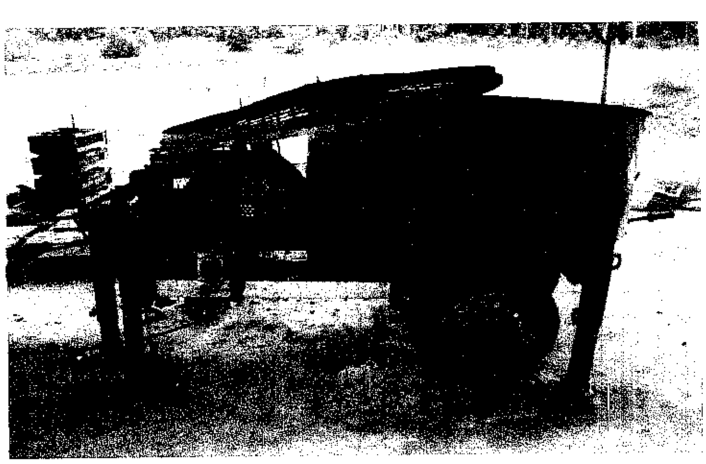

Figure 3. 2- **Mixer Machine**

Figure 3. 3- **Slump Test**

3.2.1.3 Casting

- There are 15 moulds of 150x50x150 mm cubes, 9 mould of 100x200mm split cylinder, and 3 moulds 200x300x40mm of slab were prepared for each time mix.
- The concrete mix was pour into the moulds and let it casted for 1 day before the mould can be opened.

3.2.1.4 Curing

- Curing is done after one day casted. The samples were put on the water basin for curing process.

Figure 3. 4- **Curing Tank**

3.2.1.5 Testing

- There are three tests involved in this experiment which is **compressive strength test, elastic properties test, and durability test**. Each test used different kind of machine.
- The tests of the samples depend on the duration that was stated below:

Table 3. 1 - **Testing Duration**

Samples	**Test**	**Equipment**	**Duration (days)**
Cube Test	Compressive strength	Compression strength machine	3, 7,28, 90, 120
Split Cylinder	Elastic properties/ tensile strength	Compression strength machine	3,28,90
Slab/Plank (coring)	Porosity	Desiccators	3, 7,28, 90

- Equipments / Testing methods:

For Strength

i. 2000kN Flexural and Compression Machine

- The compression strength test is used to estimate the concrete strength in a structure. The strength is calculated from the failure load divided by the cross sectional area resisting load.

- For compression test, the load is applied directly but for indirect tensile test, splitting tensile test is used. The splitting tensile strength was determined using the following equation:

$$F_t = 2P/\pi Ld, \tag{3.1}$$

- Procedure :

1. The specimen is removed from curing tank and the surface water is wiped and the specimen is grit off.
2. Each specimen is weight to the nearest kg.
3. The top and lower platens of the testing machine are cleaned. The sample is carefully centred on the lower platen and it is ensured that the load will be applied to two opposite cast faces of the sample.
4. The data is been set up depends on the size of the sample tested and the pace rate automatically set constantly. For this experiment, the rate of the cube (150x150x150mm) is 6.80 and for cylinder (200x100mm) is 0.94.
5. Without shock, the load is applied and increased continuously at a nominal rate within the range of 0.2 N/mm^2 to 0.4 N/mm^2 until no greater load can be sustained. The maximum load applied to the cube is recorded.

6. The type of failure and appearance of cracks is noted.
7. The stress of each is calculated by dividing the maximum load by the cross sectional area. For automatic machine the stress is already stated.

For Durability Test (Porosity)

i. **Coring machine**

The 300x200x40mm slabs were cored into diameter 50 x 40 mm cylinders using coring machine. This coring samples need to be used for porosity and permeability tests.

Figure 3. 5- **Coring Machine**

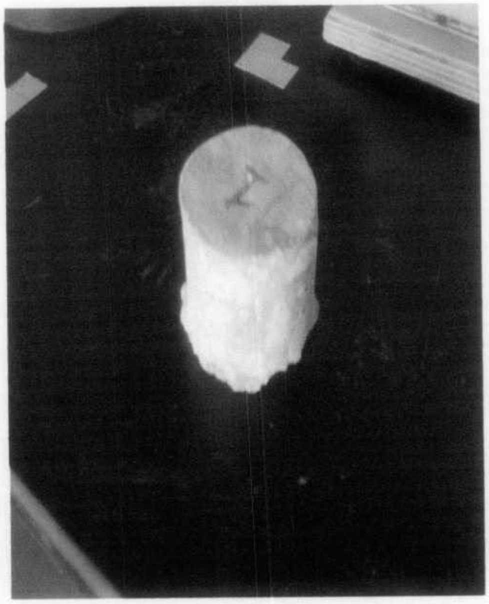

Figure 3. 6- **Core sample**

ii. **Desiccator**

This Pyrex desiccator has an approximate bowl volume of 3800mL. They are rated 1-atmosphere vacuum. This machine is used for porosity test.

Figure 3. 7- **Desiccator**

- Procedure:

1. The core samples are putted inside the vacuum desiccators for 30 minutes.
2. After 30 minutes, the desiccator is filled by water until all the samples are submerged. Experiment is run for 6 hours.
3. The desiccator is off and let the samples for overnight.
4. The next day, the samples is wipe and the weight of saturated surface dry samples in air (W_{SA}) and weight of saturated surface dry samples in water (W_{SW}) is weighted using Buoyancy Balance.
5. Then, the samples are putted in oven for 24 hours.
6. After one day, the samples are taken off and the weight of oven dry samples (W_d) is weighted.
7. The porosity can be calculated using formula:

$$P = \frac{W_{SA} - W_d}{W_{SA} - W_{SW}} \times 100 \qquad (3.2)$$

iii. Buoyancy Balance

Buoyancy Balance is weighted machine used to weight samples on air and in water.

Figure 3. 8- **Buoyancy Balance**

CHAPTER 4
RESULT AND DISCUSSION

4.1 Concrete Mix Proportion

The main objective of this research is to investigate the effects of used ground copper slag in the concrete properties. Seven (7) trials concrete mixes were prepared for each sample with the concrete weight by ratio 1(cement): 1.83(sand): 2.7(coarse): 0.45(w/c).

Table 4. 1 - **Test Variables**

CUBE TEST

Size = 150x150x150
test for = 3,7,28,90,120days
3cubes/mix/age = 3x5x7 = 105 samples

per m3	COPPER		CEMENT(kg)	WATER(kg/L)	FA (kg)	CA (kg)
	%	kg	455	205	830	1243
per trial mix = 0.07m3						
mix 1 (100%)	0	0	32	15	58	87
mix 2 (95%)	5	1.6	30.4	15	58	87
mix 3 (90%)	10	3.2	28.8	15	58	87
mix 4 (85%)	15	4.8	27.2	15	58	87
mix 5 (80%)	20	6.4	25.6	15	58	87
mix 6 (75%)	25	8	24.0	15	58	87
mix 7 (70%)	30	9.6	22.4	15	58	87

SPLIT CYLINDER

Size = 100X200mm
test for = 7,28,90 days
3cubes/mix/age = 3x3x7 = 63samples

per m3	COPPER		CEMENT(kg)	WATER(kg/L)	FA (kg)	CA (kg)
	%	kg	455	205	830	1243
per trial mix = 0.02m^3						
mix 1 (100%)	0	0	9.1	4.1	17	25
mix 2 (95%)	5	0.455	8.645	4.1	17	25
mix 3 (90%)	10	0.91	8.19	4.1	17	25
mix 4 (85%)	15	1.365	7.735	4.1	17	25
mix 5 (80%)	20	1.82	7.28	4.1	17	25
mix 6 (75%)	25	2.275	6.825	4.1	17	25
mix 7 (70%)	30	2.73	6.37	4.1	17	25

PLANK/SLAB

size plank = 200x300x40mm (2 cast)
Size cylinder = 50X40mm
test for = 3,7,28,90 days
3cubes/mix/age = 3x5x7 = 105samples

per m3	COPPER		CEMENT(kg)	WATER(kg/L)	FA (kg)	CA (kg)
	%	kg	455	205	830	1243
per trial mix = 0.072m^3						
mix 1 (100%)	0	0	33	15	60	90
mix 2 (95%)	5	1.65	31.35	15	60	90
mix 3 (90%)	10	3.3	29.7	15	60	90
mix 4 (85%)	15	4.95	28.05	15	60	90
mix 5 (80%)	20	6.6	26.4	15	60	90
mix 6 (75%)	25	8.25	24.75	15	60	90
mix 7 (70%)	30	9.9	23.1	15	60	90

The trial concrete mixes were divided into three groups. Group A was for strength test used concrete cubes, Group B for tensile strength test used split cylinders, and Group C for porosity test used slabs formwork. The variable of this experiment is a copper slag which is taken for (5, 10, 15, 20, 25, 30) % as cement replacement. For Group A and C, the tests are done for (3, 7, 28, 90, and 120) days while Group B for only (3, 28, and 90) days. The materials which are Ordinary Portland Cement Type 1 is used for all mixes because it was suitable for general concrete construction, the fine aggregate was natural sand , and the coarse aggregate was crushed gravel with the maximum size of 20mm. The used copper slag is grinded first to get smaller size than cement.

By using X-ray Fluorescene (XRF) and X-ray Diffractometry (XRD), the physical properties and chemical composition of used copper slag was obtained. However, during the lab testing, there is no result for XRD test. XRD can't detect the characteristic of the sample because the samples are already contaminated with other wasted that difficult to detect with the machine.

Table 4. 2 - **Chemical composition of used copper slag**

Chemical Composition	**Used Copper Slag (%)**
SiO_2	11.9
Al_2O_3	1.56
Fe_2O_3	73.6
CaO	2.65
MgO	0.302
SO_3	0.554
K_2O	1.13
MgO	0.302
TiO_2	0.566
Mn_2O_3	0.104
CuO	2.83
ZnO	1.91
As_2O_3	0.256
PbO	0.376
Compton	0.86
Rayleigh	1.25

The mixing process was conducted in the laboratory using a standard concrete mixer. The casting process was same for all trial mixes where 15 concrete cubes sizes of 150x150x150mm used for compressive strength test purposes, 9 split cylinders sizes 100x200mm for flexural strength test, and 3 slabs formworks from wood sizes 200x300x40mm for porosity test purposes. The tested properties for concrete mix was slump test that fix for 60 ± 5mm. the procedures of the laboratory work was explained in *Chapter 3: Methodology/ Project Work section.*

4.2 Group A : Compressive Strength

4.2.1 Data Result:

Table 4. 3 - **Compressive strength data for 3, 7, and 28, 90, and 120 days**

mix 1

day(s)	3			7			28			90			120		
weight (kg)	7.99	8.13	8.12	8.06	8.1	8.02	8.08	8.12	8.1	8.21	8.06	8.1	8.05	8.01	8.09
sample peak load(kN)	536.5	446.4	314.1	753.5	834	622	714.3	701.7	843.3	1143	1220	820.6	1092	1285	1312
sample stress(MPa)	23.85	19.84	13.96	33.49	37.07	27.69	31.75	31.18	37.48	50.8	54.21	36.47	48.55	57.13	58.3
pace rate	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Ave stress (MPa)	19.22			32.75			33.47			47.16			54.66		

mix 2

day(s)	3			7			28			90			120		
weight (kg)	8.39	8.45	8.31	8.31	8.3	8.44	8.3	8.43	8.23	8.2	8.23	8.3	8.19	8.32	8.2
sample peak load(kN)	708.4	793.1	753.8	959.7	997.7	978.7	1054	1110	1056	1150	1450	1383	1448	1519	1359
sample stress (MPa)	31.48	35.25	33.5	42.65	44.34	43.5	46.86	49.32	46.94	51.13	64.45	61.46	64.36	67.49	60.4
pace rate	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Ave stress (MPa)	33.41			43.497			47.71			59.013			64.083		

mix 3

day(s)	3			7			28			90			120		
weight (kg)	7.97	8.3	8.1	8.18	8.3	8.21	8.2	8.43	8.26	8.4	8.22	8.33	8.24	8.28	8.3
sample peak load(kN)	581.7	639.2	573.8	987.5	1163	1013	900.7	1211	1217	1477	1500	1317	1683	1332	1590
sample stress (MPa)	25.85	28.41	25.5	43.89	51.68	45.02	40.03	53.82	54.09	65.64	66.66	58.53	74.8	59.2	70.66
pace rate	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Ave stress (MPa)	26.59			46.863			49.31			63.61			68.22		

mix 4

day(s)	3			7			28			90			120		
weight (kg)	8.22	8.13	8.2	8.22	8.3	8.2	8.3	8.4	8.24	8.33	8.24	8.28	8.13	8.2	8.22
sample peak load(kN)	718.9	717.1	652.9	812.1	637.1	888.7	1113.5	1087	997.7	644.6	625.6	700.9	417.1	497	513.7
sample stress (MPa)	31.95	31.87	29.02	36.09	28.31	39.49	49.49	48.29	44.34	28.65	27.81	31.15	18.54	22.09	22.83
pace rate	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Ave stress (MPa)	30.95			34.63			47.37			29.203			21.15		

mix 5

day(s)	3			7			28			90			120		
weight (kg)	8.17	8.2	8.23	8.22	8.36	8.2	8.2	8.41	8.2	8.3	8.18	8.22	8.23	8.26	8.2
sample peak load(kN)	453	400	520.3	409.9	643	610.3	804.6	826.4	912.4	911.5	894.2	923.7	495.9	1065	974.1
sample stress (MPa)	20.14	17.78	23.12	18.22	28.58	27.12	35.76	36.73	40.55	40.51	39.74	41.05	22.06	47.33	43.29
pace rate	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Ave stress (MPa)	20.35			24.64			37.68			40.433			37.553		

mix 6

day(s)	3			7			28			90			120		
weight (kg)	8.08	8.35	8.09	8.23	8.26	8.2	8.41	8.38	8.2	8.17	8.33	8.23	8.13	8.2	8.22
sample peak load(kN)	592.8	546.2	612.7	673.2	686	654.4	903.3	880.7	988.6	1052	997.4	1071	790.3	997.3	1023
sample stress (MPa)	26.35	24.27	27.23	29.92	30.49	29.08	40.15	39.14	43.94	46.75	44.33	47.6	35.12	44.32	45.47
pace rate	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Ave stress (MPa)	25.95			29.83			41.08			46.227			41.637		

mix 7

day(s)	3			7			28			90			120		
weight (kg)	8.19	8.345	8.22	8.193	8.106	8.2	8.22	8.3	8.2	8.17	8.2	8.23	8.22	8.25	8.26
sample peak load(kN)	380.73	507	489.7	543.8	608.4	637.2	517.8	575.3	422.9	551.1	622.7	586.4	643	826.4	610.3
sample stress (MPa)	16.92	22.53	21.76	24.17	27.04	28.32	23.01	25.57	18.8	24.49	27.68	26.06	28.58	36.73	27.12
pace rate	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Ave stress (MPa)	20.4			26.51			22.46			26.077			30.81		

4.2.2 Graph Result

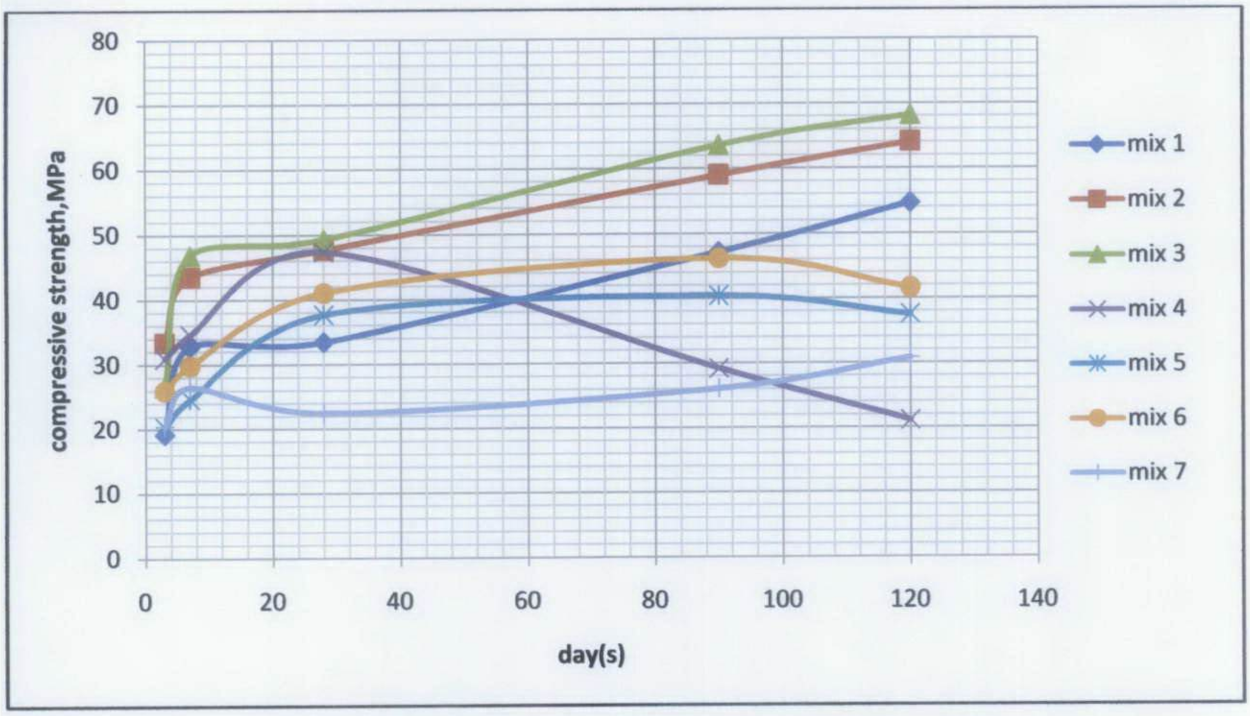

Figure 4. 1- **Graph of Compressive Strength versus days**

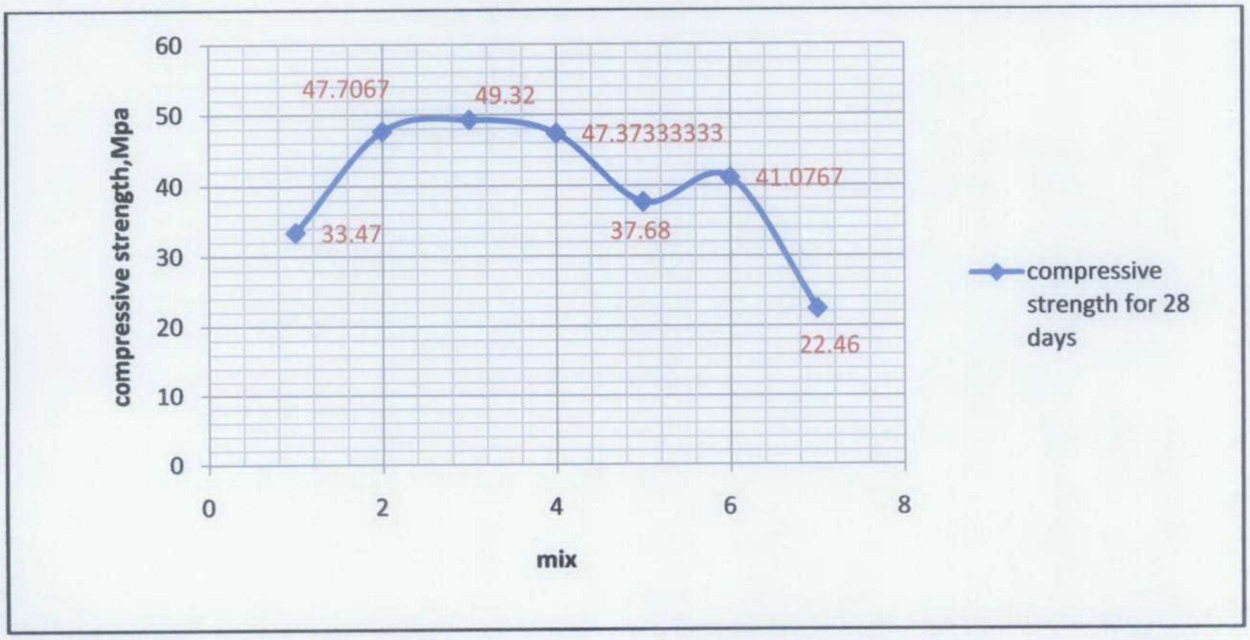

Figure 4. 2- **Graph of Compressive Strength for 28 days versus samples**

4.2.3 Discussion:

There are 7 samples tested to determine the strength. Each sample have different amount of copper slag in concrete mix. Mix 1 was used as a control (100% OPC) while mixes 2 till mix 7 were added to 5%, 10%, 15%, 20%, 25%, and 30% each of copper slag as cement replacement.

From the figure 4.1, the graph shows that the compressive strength was directly proportionally increased with the ages of the days. The strength was increased when the time was increased. The strength development depends on the temperature and humidity conditions during curing. Higher temperatures increase the speed of the chemical reaction and thus the rate of strength develop when there are more time is taken for curing. However, there are some errors occur for mix 4 and mix 7 which the value decreased when the samples up to 120 days. The possible cause that might occurs were the mixture was not compacted well and the materials was not in a good condition such as the wet aggregate, and there was others wastes mix with the materials that can effect the quality of the strength. Sometimes it might caused by the machine error when the reading was taken.

In figure 4.2, the graph shows that when the compressive strength was tested up to 28 days, the values of mix 2 up to mix 6 are highest than Mix 1 (control) whereas mix 7 is below the control line. This shows that, the strength was increased up to 25% of copper and after that the strength started to decrease such lower than the control. The percentage increased for each of the samples compared to control sample are for mix 2 (5% CS) is43%, mix 3 (10% CS) is 49%, mix 4 (15%CS) is 42%, mix 5 (20%CS) is 13% and mix 6 (25%CS) is 23%. While mix 7 (30%CS) was decreased about 33% from the control value. From the percentage, 10% of copper slag is the optimum strength that can be achieved and suitable amount for concrete mix as a cement replacement.

The bell curve of compressive strength versus samples proved that 10% of copper slag in cement replacement is the optimum value for the mean compressive strength can be achieved. This amount is the applicable value for composition in copper slag bind with the composition of cement in concrete design. There are several factors that attributed to the lower strength. One of the factors is the retardation of cement hydration due to the presence of heavy metals in copper slag. The lower strength could also be due to the fact that the very fine particles of the slag supplied a large amount of surface area per unit volume to be coated with cement (Benson et. al, 1986). This might have effectively reduced the amount of cement available for binding the fine and coarse aggregates required to provide adequate strength. There are also because of the chemical composition in copper slag that not suitable with certain amount to give strength to the concrete. There are need further research of chemicals that contain in copper slag that are contribute to the decreasing of the concrete strength.

4.2.4 Test

Figure 4. 3- **Compression Strength Test**

4.3 Group B: Tensile Strength

4.3.1 Data Result:

The tensile strength governs the cracking behavior and affects other properties such as stiffness, damping action, bond to embedded steel, and durability of concrete. It is also of importance with regard to the behavior of concrete under shear loads. The tensile strength is determined either by direct tensile tests or by indirect tensile tests such as flexural or split cylinder tests.

For this experiment, the tensile strength test is determined by indirect tensile tests which are used split cylinder test. Tensile strength test was measured for every 3, 28, and 90 days. Tensile strength was been tested using Compressive Strength Test Machine by constant pace rate 0.94. Each result for tensile strength is the average of three test values. Three cylinders were tested for splitting tensile strength (ASTM C496-96).

Table 4. 4 - **Tensile strength data for 3, 28 and 90 days**

mix 1

day(s)	3			28			90		
weight (kg)	3.71	3.69	3.75	3.73	3.72	3.73	3.75	3.74	3.71
sample peak load(kN)	75.6	77.8	73.5	105.1	119.3	145.7	112.4	149.3	185.4
sample stress (MPa)	2.41	2.48	2.34	3.35	3.8	4.64	3.578	4.751	5.903
pace rate	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Average stress (MPa)	2.41			3.93			4.744		

mix 2

day(s)	3			28			90		
weight (kg)	3.81	3.76	3.84	3.84	3.82	3.82	3.83	3.83	3.84
sample peak load(kN)	113.4	155.5	163.4	192.3	217.9	176.7	188.4	216.3	231.1
sample stress (MPa)	3.61	4.95	5.13	6.12	6.934	5.624	5.997	6.885	7.356
pace rate	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Average stress (MPa)	4.563			6.226			6.746		

mix 3

day(s)	3			28			90		
weight (kg)	3.77	3.72	3.7	3.84	3.82	3.82	3.77	3.8	3.76
sample peak load(kN)	189.9	203.5	136.7	197.9	246.1	209.7	220.1	200.7	251.8
sample stress	6.043	6.476	4.35	6.298	7.831	6.673	7.006	6.388	8.015
pace rate	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Average stress (MPa)	5.623			6.934			7.136		

mix 4

day(s)	3			28			90		
weight (kg)	3.64	3.71	3.73	3.76	3.7	3.66	3.76	3.8	3.77
sample peak load(kN)	79.1	99.8	105.1	127.9	106.7	154.2	108.1	142.3	114
sample stress	2.518	3.177	3.35	4.072	3.397	4.907	3.441	4.529	3.628
pace rate	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Average stress (MPa)	3.015			4.1253			3.866		

mix 5

day(s)	3			28			90		
weight (kg)	3.74	3.7	3.72	3.73	3.7	3.76	3.77	3.8	3.78
sample peak load(kN)	76.4	76.8	77.8	118.5	80.8	137.4	119.2	134.6	118.5
sample stress	2.43	2.446	2.48	3.771	2.572	4.372	3.796	4.283	3.771
pace rate	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Average stress (MPa)	2.452			3.5717			3.95		

mix 6

day(s)	3			28			90		
weight (kg)	3.8	3.77	3.75	3.81	3.77	3.8	3.69	3.77	3.79
sample peak load(kN)	63	57.8	73.5	97.3	92.2	100.1	128.1	87.5	108.1
sample stress	2.005	1.839	2.34	3.097	2.935	3.185	4.077	2.784	3.441
pace rate	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Average stress (MPa)	2.061			3.0723			3.434		

mix 7

day(s)	3			28			90		
weight (kg)	3.8	3.66	3.79	3.78	3.77	3.77	3.8	3.77	3.75
sample peak load(kN)	72.8	63.9	80.8	62.8	49.9	54.3	55.7	50.7	47.8
sample stress	2.318	2.034	2.572	2	1.589	1.728	1.773	1.614	1.525
pace rate	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Average stress (MPa)	2.308			1.7723			1.637		

4.3.2 Graph Result:

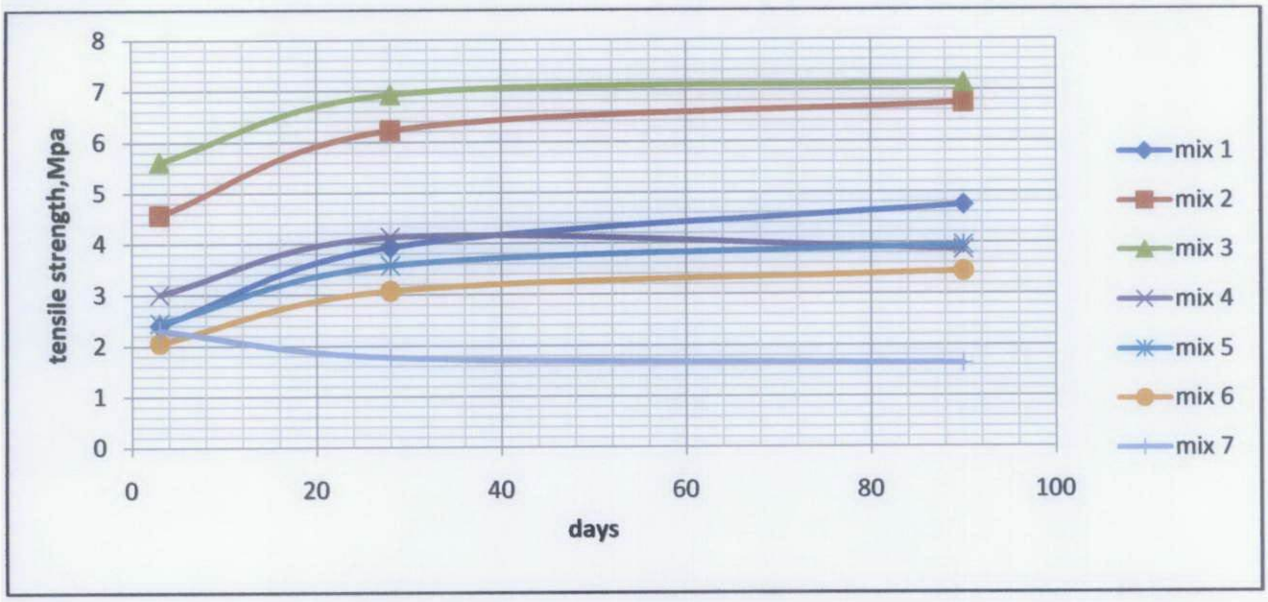

Figure 4. 4- Graph of Tensile Strength versus days

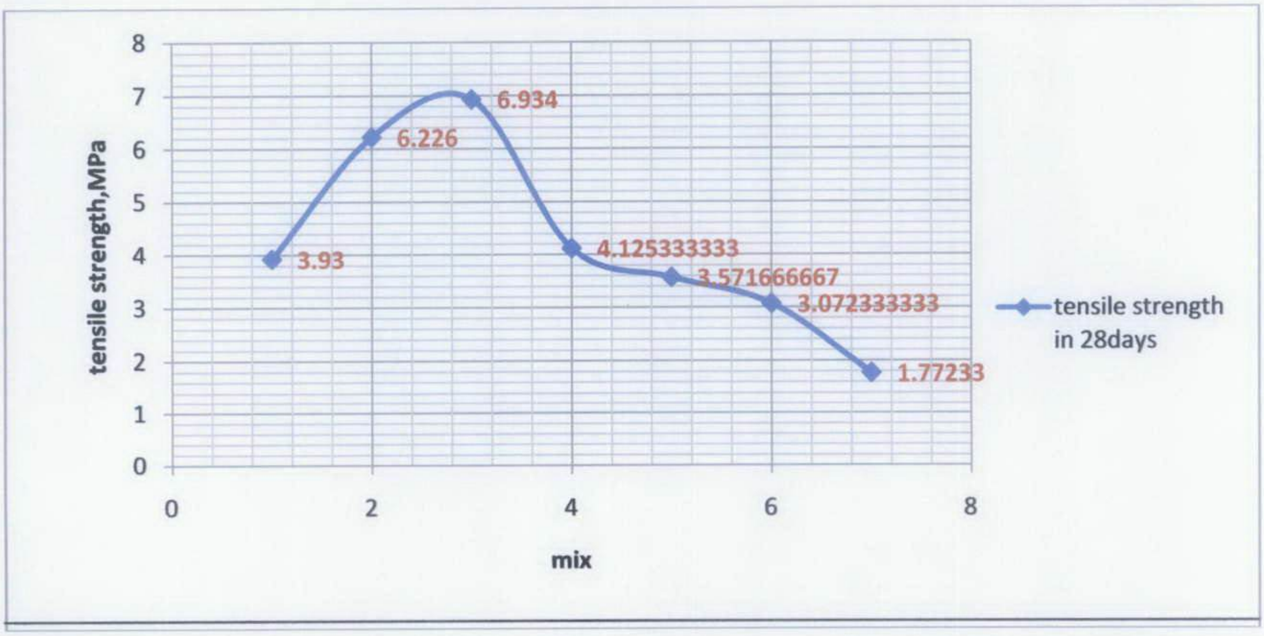

Figure 4. 5- Graph of Tensile Strength for 28 days versus samples

4.3.3 Discussion:

The tensile strength governs the cracking behavior and affects other properties such as stiffness, damping action, bond to embedded steel, and durability of concrete. It is also of importance with regard to the behavior of concrete under shear loads. There are 7 samples tested to determine the tensile strength using split cylinder. Each sample have different amount of copper slag in concrete mix. Mix 1 was used as a control (100% OPC) while mixes 2 till mix 7 were added to 5%, 10%, 15%, 20%, 25%, and 30% each of copper slag as cement replacement.

From the figure 4.4, the graph shows that the tensile strength was increased up to 28 days but became inconsistent towards after that. Some samples were consistently increased up to 90 days but some samples started to decrease after 28 days. Mix 1(control), mix 2 (5%), mix 3(10%), mix 5 (20%), and mix 6 (25%) were increased when the ages increased but mix 4 (15%) form a bell curve which the peak strength were only up to 28 days. For mix 7 (30%), the strength was very weak even though due to ages. There are several factors that contribute to the inconsistency of the values such as the mixture was not compacted well, the materials was not in a good condition such as the wet aggregate, and there was others wastes mix with the materials that can effect the quality of the strength. Sometimes it might caused by the machine error when the reading was taken.

In figure 4.5, the graph shows that when the tensile strength was tested up to 28 days, the values of mix 2 up to mix 4 were highest than Mix 1 (control) whereas mix 5, mix 6, and mix 7 were below the control line. This shows that, the strength was increased up to 15% of copper and after that the strength started to decrease such lower than the control. The percentage increased for each of the samples compared to control sample were mix 2 (5% CS) is 58%, mix 3 (10% CS) is 76%, and mix 4 (15%CS) is 5%. Whereas mix 5 (20%CS), mix 6 (25%), and mix 7 (30%) were decreased about 9%, 28%, and 58% from the control value. From the percentage, 10% of copper slag is the optimum strength that can be achieved and suitable amount for concrete mix as a cement replacement. In a two-year study to obtain "optimum" high performance concrete based on cement dosage, dosage of superplasticizer, addition of silica fume, and selection of size and shape of aggregates, Charif et al. (1990) found that the tensile strength could be increased by 40 to 60% over the normal strength concrete. Regarding the effect of freezing and thawing, Marzouk and Jiang (1994) reported that after 700 cycles, the modulus of rupture of high strength concrete was reduced by 15% whereas the reduction was 60% for normal strength concrete.

The bell curve of tensile strength versus samples proved that 10% of copper slag in cement replacement is the optimum value for the mean tensile strength can be achieved. This amount is the applicable value for composition in copper slag bind with the composition of cement in concrete design to have better cracking behavior and affects other properties such as stiffness, damping action, bond to embedded steel, durability of concrete and behavior of concrete under shear loads.

4.3.4 Test:

Figure 4. 6- Tensile Strength Test

4.4 Group C: Porosity

4.4.1 Data Results:

Table 4. 5- Porosity data for 3, 7, and 28, and 90 days

mix 1

day(s)	3			7			28			90		
weight in air (g)	266.6	269.5	262.1	271.2	263.6	268.2	225.6	226.7	225.1	234.1	91.7	220.7
weight in water(g)	117.2	118	118.6	120.1	115.9	117.5	103.5	103.6	93.5	91.7	93.7	97
weight dry	250.9	253.5	246	257.4	249.7	253.3	214.5	214.6	213.4	220.7	216	221.2
porosity	10.76			9.48			9.26			7.3		

mix 2

day(s)	3			7			28			90		
weight in air (g)	258.8	252.3	255.6	255.8	255.8	252.2	244.5	225.3	223.4	235.6	247	217.2
weight in water(g)	116.6	111.4	114	109.4	110	108.3	104.5	105.4	92.2	99.7	92.3	90
weight dry	244	236.4	239.8	240.1	240.7	237.7	231.5	213.7	210	230.1	235	200.4
porosity	10.95			10.39			9.72			8.25		

mix 3

day(s)	3			7			28			90		
weight in air(g)	236.3	242	241.3	239.5	236.6	239.1	243.2	241	239.3	243.2	243	240
weight in water(g)	101.7	105.4	105.6	99.7	98.7	103.1	104.5	105.1	101.5	97.6	94.3	93.1
weight dry	220.6	225.9	226.1	223.5	222.1	222.7	229.9	229.5	226.9	230	229	229.5
porosity	11.55			11.33			9.00			8.59		

mix 4

day(s)	3			7			28			90		
weight in air(g)	256.1	262	250.8	252	256.9	256	245.8	241	244.4	252.5	246	254.2
weight in water(g	113	112.9	109.3	108.2	110.3	109.1	105.8	102	104.9	100	103	105.8
weight dry	238.2	245.7	233	237.2	240.7	239.6	232.8	226.8	230.1	227.2	230	229.7
porosity	11.99			10.84			9.91			13.67		

mix 5

day(s)	3			7			28			90		
weight in air(g)	251.7	239.6	244.4	236.7	240.1	236.3	240.7	235	240.1	253.2	240	243.6
weight in water(g)	111.7	104.3	97	99.7	101.6	98.9	101.4	107.7	100.5	104.8	102	102
weight dry (g)	237	224.4	211.5	232.2	226.5	222.2	220.5	225.8	222.3	228.8	225	237.2
porosity	14.85			7.8			11.77			10.68		

mix 6

day(s)	3			7			28			90		
weight in air (g)	238.8	241.5	248	244.2	237.6	246	222.6	242.7	246.7	227.6	221	243.6
weight inwater(g)	104.2	102.7	104.8	102.6	98.7	103.9	92.3	101.7	106.5	104.8	92.7	114.4
weight dry	225	227.8	233.7	211.7	230.8	234.8	211.1	231.2	228.9	208.9	244	214.7
porosity	10.04			11.95			9.92			6.46		

mix 7

day(s)	3			7			28			90		
weight in air (g)	215.3	204.5	210.4	225.1	233.7	230.6	237.1	246.8	242.9	249.4	233	245.6
weight in water(g)	86.1	78.1	81.3	94.8	91.7	82.2	99.2	104.6	102.4	105.5	105	101.7
weight dry	184.3	200.1	192.6	208.6	207.1	208.9	217.3	209.8	219.9	235.2	217	229.5
porosity	13.83			15.4			18.97			11.05		

4.4.2 Graph Results:

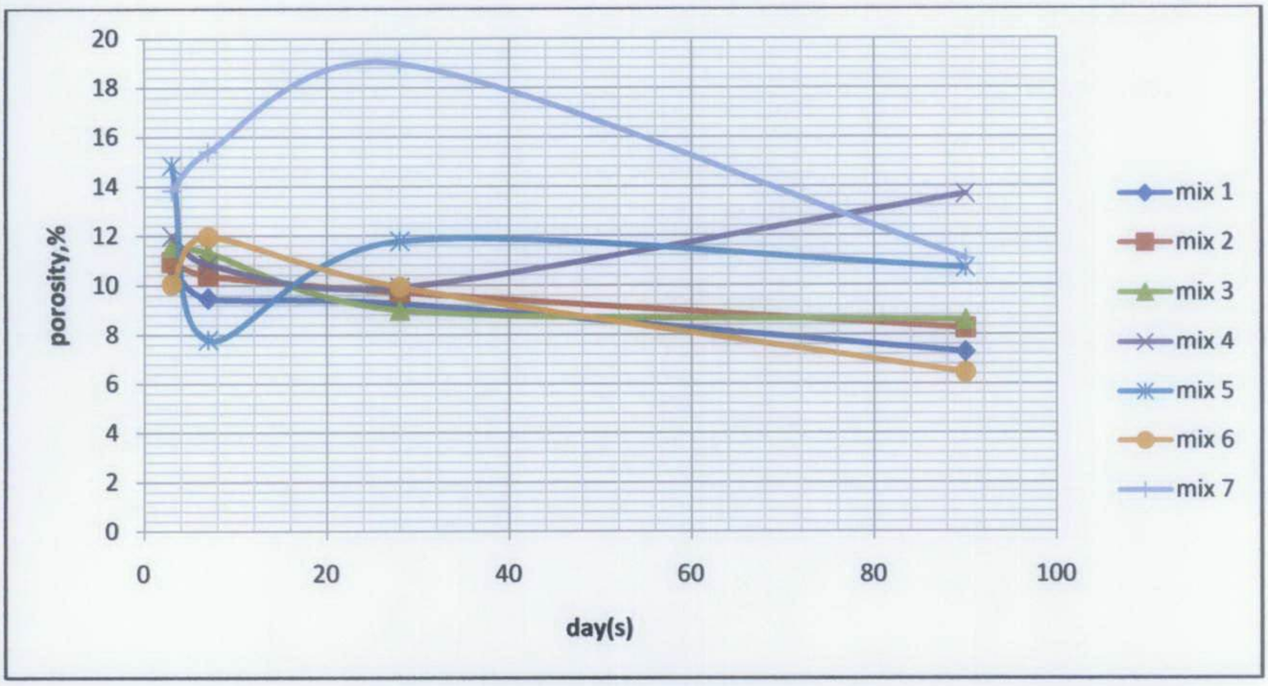

Figure 4. 7- Graph of Porosity versus days

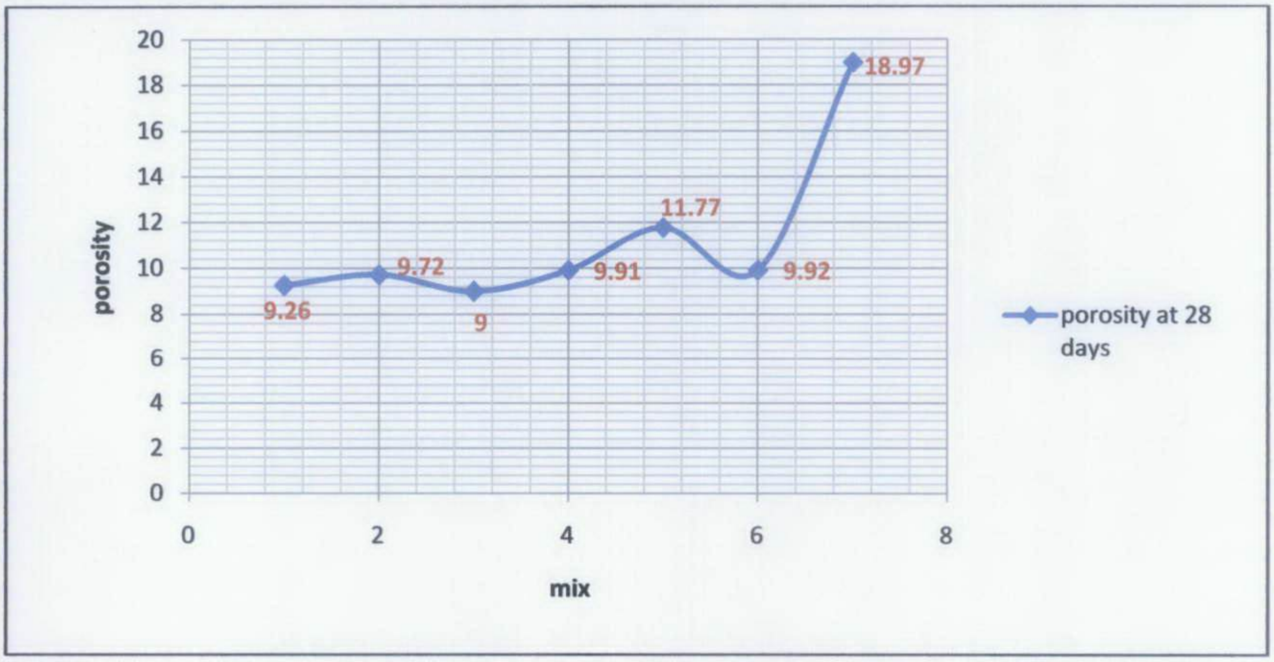

Figure 4. 8- Graph of Porosity for 28 days versus samples

4.4.3 Discussion:

There are 7 samples tested to determine the porosity. Each sample have different amount of copper slag in concrete mix. Mix 1 was used as a control (100% OPC) while mixes 2 till mix 7 were added to 5%, 10%, 15%, 20%, 25%, and 30% each of copper slag as cement replacement.

From the figure 4.7, the graph shows that the porosity of mix 1, mix 2 and mix 3 were decreased linearly due to ages up to 90 days. The chemical reaction of lime crystals to form binders has a direct effect of increased paste density, reduced porosity over time, and will enhance the matrix chemical resistance to many aggressive species. The reading of porosity became inconsistent for mix 4 to mix 7. Theoretically, the more lower the porosity, the more good of the concrete itself. Mix 1, mix 2 and mix 3 have a good concrete behavior because the porosity decreased due to ages, but mix 4, mix 5 and mix 6 have an unstable reading due to ages so that it is not considerable can contribute to the development of the concrete properties. For mix 7 (30%), the concrete properties was very weak because more porosity produce due to ages.

In figure 4.8, the graph shows that when the porosity was tested up to 28 days, only mix 3 (10%CS) have a lower value compare to control mix. The value of mix 3 was decreased about 2.8%, while others were increased such as for mix 2 up to 45%, mix 4, 7%, mix 5, 27%, mix 6, 7% and mix 7 around 104% compare to mix 1(control). From the percentage, 10% of copper slag has lowest value of porosity so that is give highest durability in concrete. When the durability increased, the strength of the concrete also increased. This means that 10% of copper slag as cement replacement is the optimum value to achieved an optimum strength in concrete design

It should be noted that although aggregates are porous, their pores are normally discontinuous in a concrete matrix, being completely enveloped by cement paste. Discrete voids or pores in concrete, including entrained air bubbles that are discontinuous similarly do not contribute significantly to concrete permeability. Concrete porosity is usually expressed in terms of percentage by volume of concrete. It is the interconnectivity of pores, rather that total porosity that determines a concrete's permeability. A concrete with a high proportion of disconnected pores may be less permeable that a concrete with a much smaller proportion of connected, or continuous pores. With greater particularity, it is the overall nature of the matrix pore structure that ultimately affects its permeability. The size, distribution, interconnectivity, and shape of pores are all determining factors in the overall permeability of a concrete matrix.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This paper presented the results of a research study on the effect of using ground copper slag as a partial substitute for portland cement in concrete mixtures. After one year research and work on experiment, the results shows meet the objectives of the project. Copper Slag is one of the pozzolan that enhanced the strength and durability of the concrete and as a cement replacement for some economical and environmental friendly.

There are seven (7) samples used as parameters. One is a control sample and others represent percentages of copper slag in cement replacement. There are 5%, 10%, 15%, 20%, 25%, and 30% of copper slag used in concrete mix to determine the highest percentage to achieve optimum strength. The samples were evaluated for compressive strength, tensile strength, and porosity tests due to ages for 3, 7, 28, 90 and 120 days. The reliability and consistency of the three (3) tests shows that 10% of the copper slag as cement replacement is the maximum value for optimum strength and durability of concrete can be achieved. This is expected since copper slag has a low free lime content of 6% compared with 63% free lime in portland cement.

5.2 Project benefits

Aspects	Advantages
Quality	- Enhance the characteristic of concrete - Increase the strength and durability in concrete mixture - Better quality concrete mixture with lower cost
Cost	- Reduce cement cost - Economically - Turn the waste material to the value material
Environmental Impacts	- Conserves natural resources and energy - Reduce industry waste - Reduce pollution - Reduce landfill disposal of used copper slag - Prevent solid/hazardous waste of heavy metal in used copper slag - Environmental friendly

5.3 Recommendations

- The used copper slag should be sieve to separate the order contaminated waste so that it can give more high value of the results.
- Hydrated lime should be added as an activator to pozzolanic reactions because copper slag must have a sufficient quantity of lime to reach the required rate of hydration and to achieve the required early age strength.
- Further study on microstructure of copper slag should be done.
- Testing on beam and column using other methods such as dynamic and elastic load, and permeability tests.

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APPENDICES

APPENDIX A – Result of the Copper Slag Composition (XRF Test)

APPENDIX B – Concrete Mix Design

APPENDIX C – Test Results for Compressive, Tensile Strength and Porosity

APPENDIX D – Gantt chart

APPENDIX A

ıted by Eval on 26-Sep-2007 09:33:00
nple :Sample 1-Fatin
nple measured on 26-Sep-2007 09:14:05

O	Mg	Al	Si	S	K	Ca
	1.3 KCps	4.5 KCps	35.6 KCps	3.9 KCps	18.2 KCps	38.1 KCps
32.3 %	0.182 %	0.826 %	5.55 %	0.222 %	0.942 %	1.89 %

Ti	Cr	Mn	Fe	Cu	Zn	As
9.3 KCps	2.1 KCps	3.1 KCps	2300.2 KCps	83.7 KCps	87.1 KCps	5.1 KCps
.339 %	0.0386 %	0.0809 %	51.5 %	2.26 %	1.54 %	0.194 %

Sr	Zr	Mo	Tb	Re	Os	Pb
9.1 KCps	10.5 KCps	92.0 KCps	8.4 KCps	8.7 KCps	16.0 KCps	11.6 KCps
)680 %	0.0557 %	0.538 %	0.188 %	0.624 %	0.0148 %	0.349 %

:ompton	Rayleigh	Norm.
0.86	1.25	100.00 %

26/7/07.

APPENDIX B
CONCRETE MIX DESIGN

1.1	Characteristic strength	Specified	compressive 50 N/mm² at 28 days; Proportion defective 1 per cent
1.2	Standard deviation	Fig 3	5 N/mm² or no data ____ N/mm²
1.3	Margin	C1	(k = 2.33) 2.33 × 5 = 11.65 N/mm²
1.4	Target mean strength	C2	50 + 11.6 = 62 N/mm²
1.5	Cement type	Specified	OPC/~~SRPC/RHPC~~
1.6	Aggregate type: coarse Aggregate type: fine		Crushed Uncrushed
1.7	Free-water/cement ratio	Table 2, Fig 4	0.46 — Use the lower value
1.8	*Maximum free-water/cement ratio*	*Specified*	0.45
2.1	Slump or V-B	Specified	Slump 60–180 mm or V-B – s
2.2	Maximum aggregate size	Specified	20 mm
2.3	Free-water content	Table 3	205 kg/m³
3.1	Cement content	C3	205 ÷ 0.45 = 455 kg/m³
3.2	*Maximum cement content*	*Specified*	____ kg/m³
3.3	*Minimum cement content*	*Specified*	370 kg/m³ — Use if greater than Item 3.1 and calculate Item 3.4
3.4	Modified free-water/cement ratio		
4.1	Relative density of aggregate (SSD)		2.9 known/assumed
4.2	Concrete density	Fig 5	2733 kg/m³
4.3	Total aggregate content	C4	2733 – 455 – 205 = 2073 kg/m³
5.1	Grading of fine aggregate	BS 882	Zone 2
5.2	Proportion of fine aggregate	Fig 6	40 per cent
5.3	Fine aggregate content	C5	2073 × 0.4 = 830 kg/m³
5.4	Coarse aggregate content	C5	2073 – 830 = 1243 kg/m³

Quantities	Cement (kg)	Water (kg or l)	Fine aggregate (kg)	Coarse aggregate (kg)
per m³ (to nearest 5 kg)	455	205	830	1243
per trial mix of ____ m³				

n italics are optional limiting values that may be specified (see Section 7).

m² = 1 MN/m² = 1 MPa (see footnote on page 8).

APPENDIX B

CUBE TEST

Size = 150x150x150
test for = 3,7,28,90,180days
3cubes/mix/age = 3x5x7 = 105 samples

per m3	COPPER		CEMENT(kg)	WATER(kg/L)	FA (kg)	CA (kg)
	%	kg	455	205	830	1243
per trial mix = 0.07m3						
mix 1 (100%)	0	0	32	15	58	87
mix 2 (95%)	5	1.6	30.4	15	58	87
mix 3 (90%)	10	3.2	28.8	15	58	87
mix 4 (85%)	15	4.8	27.2	15	58	87
mix 5 (80%)	20	6.4	25.6	15	58	87
mix 6 (75%)	25	8	24.0	15	58	87
mix 7 (70%)	30	9.6	22.4	15	58	87

SPLIT CYLINDER

Size = 100X200mm
test for = 7,28,90 days
3cubes/mix/age = 3x3x7 = 63samples

per m3	COPPER		CEMENT(kg)	WATER(kg/L)	FA (kg)	CA (kg)
	%	kg	455	205	830	1243
per trial mix = 0.02m3						
mix 1 (100%)	0	0	9.1	4.1	17	25
mix 2 (95%)	5	0.455	8.645	4.1	17	25
mix 3 (90%)	10	0.91	8.19	4.1	17	25
mix 4 (85%)	15	1.365	7.735	4.1	17	25
mix 5 (80%)	20	1.82	7.28	4.1	17	25
mix 6 (75%)	25	2.275	6.825	4.1	17	25
mix 7 (70%)	30	2.73	6.37	4.1	17	25

PLANK/SLAB

size plank = 200x300x40mm (3 cast)
Size cylinder = 50X40mm
test for = 3,7,28,90,180
days
3cubes/mix/age = 3x5x7 = 105samples

per m3	COPPER		CEMENT(kg)	WATER(kg/L)	FA (kg)	CA (kg)
	%	kg	455	205	830	1243
per trial mix = 0.072m3						
mix 1 (100%)	0	0	33	15	60	90
mix 2 (95%)	5	1.65	31.35	15	60	90
mix 3 (90%)	10	3.3	29.7	15	60	90
mix 4 (85%)	15	4.95	28.05	15	60	90
mix 5 (80%)	20	6.6	26.4	15	60	90
mix 6 (75%)	25	8.25	24.75	15	60	90
mix 7 (70%)	30	9.9	23.1	15	60	90

APPENDIX C

LABORATORY TESTS RESULT

CUBE TEST (Compressive Strength Test)					
Marking	**Date cure**	**Days**	**Date of Test**	**Sample Peak Load (kN)**	**Stress (N/mm^2)**
Control Mix 1	22/8/07	3	25/8/07	536.5	23.85
				446.4	19.84
				314.1	13.96
		7	28/8/07	353.5	33.49
				834	37.07
				622	27.69
		28	18/9/07	714.3	31.75
				701.7	31.18
				843.3	37.48
		90	19/11/07	1143	50.8
				1220	54.21
				820.6	36.47
		120	19/12/07	1092	48.55
				1285	57.13
				1312	58.3
Mix 2 (5%CS)	5/10/2007	3	8/10/2007	708.4	31.48
				793.1	35.25
				753.8	33.5
		7	12/10/2007	959.7	42.65
				997.7	44.34
				978.7	43.5
		28	2/11/2007	1054	46.86
				1110	49.32
				1056	46.94
		90	4/1/2008	1150	51.13
				1450	64.45
				1383	61.46
		120	3/2/2008	1448	64.36
				1519	67.49
				1359	60.4
Mix 3 (10%CS)	27/10/07	3	31/10/07	581.7	25.85
				639.2	28.41
				573.8	25.5
		7	4/11/2007	987.5	43.89
				1163	51.68
				1013	45.02
		28	25/11/07	900.7	40.03
				1211	53.82
				1217	54.09

		90	26/1/08	1477	65.64
				1500	66.66
				1317	58.53
		120	26/2/08	1683	74.8
				1332	59.2
				1590	70.66
Mix 4 (15%CS)	3/12/2007	3	6/12/2007	718.9	31.95
				717.1	31.87
				652.9	29.02
		7	10/12/2007	812.1	36.09
				637.1	28.31
				888.7	39.49
		28	31/12/07	1113.5	49.49
				1087	48.29
				997.7	44.34
		90	2/3/2008	644.6	28.65
				625.6	27.81
				700.9	31.15
		120	1/4/2008	417.1	18.54
				497	22.09
				513.7	22.83
Mix 5 (20%CS)	4/12/2007	3	7/12/2007	453	20.14
				400	17.78
				520.3	23.12
		7	11/12/2007	409.9	18.22
				643	28.58
				610.3	27.12
		28	1/1/2008	804.6	35.76
				826.4	36.73
				912.4	40.55
		90	3/3/2008	911.5	40.51
				894.2	39.74
				923.7	41.05
		120	2/4/2008	495.9	22.04
				1065	47.33
				974.1	43.29
Mix 6 (25%CS)	6/12/2007	3	9/12/2007	592.8	26.35
				546.2	24.27
				612.7	27.23
		7	13/12/07	673.2	29.92
				686	30.49
				654.4	29.08
		28	13/12/07	903.3	40.15
				880.7	39.14
				988.6	43.94
		90	5/3/2008	1052	46.75
				997.4	44.33

				1071	47.6
		120	4/4/2008	790.3	35.12
				997.3	44.32
				1023	45.47
Mix 7 (30%CS)	7/1/2008	3	10/1/2008	380.73	16.92
				507	22.53
				489.7	21.76
		7	14/1/08	543.8	24.17
				608.4	27.04
				637.2	28.32
		28	4/2/2008	517.8	23.01
				575.3	25.57
				422.9	18.8
		90	6/4/2008	551.1	24.49
				622.7	27.68
				586.4	26.06
		120	6/5/2008	643	28.58
				826.4	36.73
				610.3	27.12

SPLIT CYLINDER (Tensile Strength Test)					
Marking	**Date cure**	**Days**	**Date of Test**	**Sample Peak Load (kN)**	**Stress (N/mm²)**
Control Mix 1	13/9/07	3	20/9/07	75.6	2.41
				77.8	2.48
				73.5	2.34
		28	11/10/2007	105.1	3.35
				119.3	3.8
				145.7	4.64
		90	11/12/2007	112.4	3.578
				149.3	4.751
				185.4	5.903
Mix 2 (5%CS)	5/10/2007	3	8/10/2007	113.4	3.61
				155.5	4.95
				163.4	5.13
		28	2/11/2007	192.3	6.12
				217.9	6.934
				176.7	5.624
		90	4/1/2008	188.4	5.997
				216.3	6.885
				231.1	7.356
Mix 3 (10%CS)	27/10/07	3	31/10/07	189.9	6.043
				203.5	6.476
				136.7	4.35
		28	25/11/07	197.9	6.298
				246.1	7.831
				209.7	6.673
		90	26/1/08	220.1	7.006
				200.7	6.388
				251.8	8.015
Mix 4 (15%CS)	3/12/2007	3	6/12/2007	79.1	2.518
				99.8	3.177
				105.1	3.35
		28	31/12/07	127.9	4.072
				106.7	3.397
				154.2	4.907
		90	2/3/2008	108.1	3.441
				142.3	4.529
				114	3.628
Mix 5 (20%CS)	4/12/2007	3	7/12/2007	76.4	2.43
				76.8	2.446
				77.8	2.48
		28	1/1/2008	118.5	3.771
				80.8	2.572
				137.4	4.372
				119.2	3.796

		90	3/3/2008	134.6	4.283
				118.5	3.771
Mix 6 (25%CS)	6/12/2007	3	9/12/2007	63	2.005
				57.8	1.839
				73.5	2.34
		28	3/1/2008	97.3	3.097
				92.2	2.935
				100.1	3.185
		90	5/3/2008	128.1	4.077
				87.5	2.784
				108.1	3.441
Mix 7 (30%CS)	28/1/08	3	31/1/08	72.8	2.318
				63.9	2.034
				80.8	2.572
		28	25/2/08	62.8	2
				49.9	1.589
				54.3	1.728
		90	27/4/08	55.7	1.773
				50.7	1.614
				47.8	1.525

PLANK (Porosity Test)							
arking	Date cure	Days	Date of Test	Weight in air(g)	weight in water	weigth dry (g)	porosity
;ontrol Mix 1	28/1/08	3	31/1/08	266.6	117.2	250.9	10.76
				269.5	118	253.5	
				262.1	118.6	246	
		7	4/2/2008	271.2	120.1	257.4	9.48
				263.6	115.9	249.7	
				268.2	117.5	253.3	
		28	25/2/08	225.6	103.5	214.5	9.26
				226.7	103.6	214.6	
				225.1	93.5	213.4	
		90	27/4/08	234.1	91.7	220.7	7.3
				224.6	93.7	216	
				229.1	97	221.2	
Mix 2 5%CS)	24/1/08	3	27/1/08	258.8	116.6	244	10.95
				252.3	111.4	236.4	
				255.6	114	239.8	
		7	31/1/08	255.8	109.4	240.1	10.39
				255.8	110	240.7	
				252.2	108.3	237.7	
		28	18/2/08	244.5	104.5	231.5	9.72
				225.3	105.4	213.7	
				223.4	92.2	210	
		90	20/4/08	235.6	99.7	230.1	8.25
				247	92.3	235	
				217.2	90	200.4	
Mix 3 10%CS)	25/1/08	3	28/1/08	236.3	101.7	220.6	11.55
				242	105.4	225.9	
				241.3	105.6	226.1	
		7	1/2/2008	239.5	99.7	223.5	11.33
				236.6	98.7	222.1	
				239.1	103.1	222.7	
		28	19/2/08	243.2	104.5	229.9	9
				241	105.1	229.5	
				239.3	101.5	226.9	
		90	21/4/08	243.2	97.6	230	8.59
				243	94.3	229	
				240	93.1	229.5	
Mix 4 15%CS)	26/1/08	3	29/1/08	256.1	113	238.2	11.99
				262	112.9	245.7	
				250.8	109.3	233	
		7	2/2/2008	252	108.2	237.2	10.84
				256.9	110.3	240.7	
				256	109.1	239.6	

		28	23/2/08	245.8	105.8	232.8	9.91
				241	102	226.8	
				244.4	104.9	230.1	
		90	24/4/08	252.5	100	227.2	13.67
				246	103	230	
				254.2	105.8	229.7	
Mix 5 (0%CS)	26/1/08	3	29/1/08	251.7	111.7	237	14.85
				239.6	104.3	224.4	
				244.4	97	211.5	
		7	2/2/2008	236.7	99.7	232.2	7.8
				240.1	101.6	226.5	
				236.3	98.9	222.2	
		28	23/2/08	240.7	101.4	220.5	11.77
				235	107.7	225.8	
				240.1	100.5	222.3	
		90	24/4/08	253.2	104.8	228.8	10.68
				240	102	225	
				243.6	102	237.2	
Mix 6 (5%CS)	28/1/08	3	31/1/08	238.8	104.2	225	10.04
				241.5	102.7	227.8	
				248	104.8	233.7	
		7	4/2/2008	244.2	102.6	211.7	11.95
				237.6	98.7	230.8	
				246	103.9	234.8	
		28	25/2/08	222.6	92.3	211.1	9.92
				242.7	101.7	231.2	
				246.7	106.5	228.9	
		90	27/4/08	227.6	104.8	208.9	6.46
				221	92.7	244	
				243.6	114.4	214.7	
Mix 7 (30%CS)	28/1/08	3	31/1/08	215.3	86.1	184.3	13.83
				204.5	78.1	200.1	
				210.4	81.3	192.6	
		7	4/2/2008	225.1	94.8	208.6	15.4
				233.7	91.7	207.1	
				230.6	82.2	208.9	
		28	25/2/08	237.1	99.2	217.3	18.97
				246.8	104.6	209.8	
				242.9	102.4	219.9	
		90	27/4/08	249.4	105.5	235.2	11.05
				233	105	217	
				245.6	101.7	229.5	

FINAL YEAR PROJECT 1 (SEMESTER 1)

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Selection of Project Topic	■															
	-Propose Topic																
	-Topic assigned to students																
2	Preliminary Research Work		■	■													
	-Introduction																
	-Objective																
	-List of references/literature																
	-Project planning																
3	Submission of Preliminary Report		●														
4	Project Work				■	■	■	■									
	-Reference/Literature																
5	Laboratory Work							■	■	■	■	■	■	■	■	■	■
	-Mixing/Casting Sample																
	-Testing																
6	Submission of Interim Report Final Draft															●	
7	Oral Presentation																●

● Suggested milestone

■ Process

FINAL YEAR PROJECT 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
1	FYP Topic Confirmation	■															
2	Project Work Continue		■	■													
	-Mixing samples																
	-Testing																
3	Submission of Progress Report 1			■													
4	Laboratory Work Continue				■	■	■	■	■	■	■	■	■	■			
	-Testing																
5	Submission of Progress Report 2							●									
6	Poster Exhibition										●						
7	EDX												●				
8	Submission of 1st draft											●					
9	Submission of Final Report														●		
10	Presentation																●

● Suggested milestone(TBA)

■ Process